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Forest Health Protection

Pacific Southwest Region
Northeastern California Shared Service Area

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To: District Ranger, Warner Mountain Ranger District, Modoc National Forest

Subject: Forest insect and disease evaluation of the Fandango Project (FHP Report NE18-08)

Summary

At the request of Peter Hall, District Silviculturist, Warner Mountain Ranger District, Danny Cluck, Forest Health Protection Entomologist, conducted a field evaluation of the Fandango Project on June 28, 2018. The objective of this visit was to evaluate current stand conditions, determine the impacts of forest insects and diseases on management objectives and discuss treatment alternatives. Recommendations provided in this report will assist in the formulation of silvicultural prescriptions aimed at reducing stand density and increasing resiliency to disturbance events such as insect outbreaks, drought and fire.

Key findings:

- White fir abundance has increased dramatically within the project area due in large part to fire exclusion. White fir is now the dominant conifer species in many stands that were historically dominated by fire-adapted ponderosa pine.
- Very high levels of recent fir engraver beetle-caused white fir mortality is evident throughout the project area (Figure 1).
- Mortality of ponderosa pine is occurring at lower elevations due to attacks by western pine beetle.
- Overstocking is putting many stands at risk to high levels of bark beetle-caused tree mortality during periods of drought.
- Green tree thinning, sanitation and salvage are highly recommended throughout the project area to greatly reduce the abundance of white fir, decrease surface and ladder fuels and begin to restore what was once a fire-adapted ponderosa pine dominated ecosystem. Specific recommendations are provided in this evaluation.

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Description of the project area

The Fandango project is located approximately 4 miles east of Willow Ranch, CA at elevations ranging between 5,150 and 7,773 feet (41.880754° N and 120.258994° W). Annual precipitation ranges between 20 and 35 inches (Figure 2). Forest cover at lower elevations and south facing slopes consist primarily of ponderosa pine (*Pinus ponderosa*) transitioning into ponderosa pine and white fir (*Abies concolor*) at higher elevations and more northerly aspects. The highest elevations within the project area are mixed conifer with ponderosa pine, white fir, lodgepole pine (*Pinus contorta var. murrayana*) and western white pine (*Pinus monticola*). Incense cedar (*Calocedrus decurrens*) is also found in some locations and quaking aspen (*Populus tremuloides*) stands are found along riparian areas. Most forested areas are densely stocked, have experienced elevated levels of tree mortality associated with insects, pathogens and drought and contain high numbers of standing and down dead trees.

Management objectives

The Fandango project proposes to reduce fuels and improve forest health through thinning and prescribed burning. Stocking targets for ponderosa pine stands will reduce susceptibility to bark beetles and will be generally lower than higher elevation white fir and mixed conifer stands. Residual stands will be more open, increasing the amount of available soil moisture and sunlight for individual trees. White fir abundance will be substantially reduced in lower and mid-elevation stands.

Figure 1. Recent white fir mortality caused by fir engraver beetle in the Fandango project area.

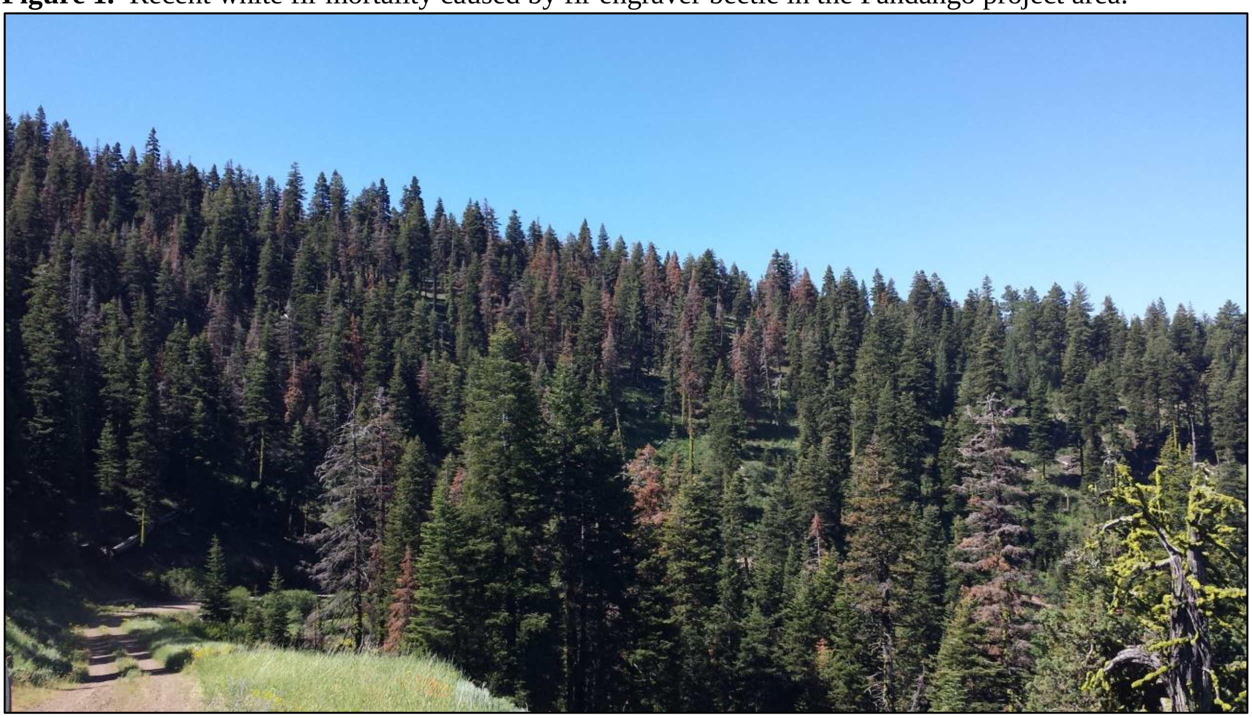
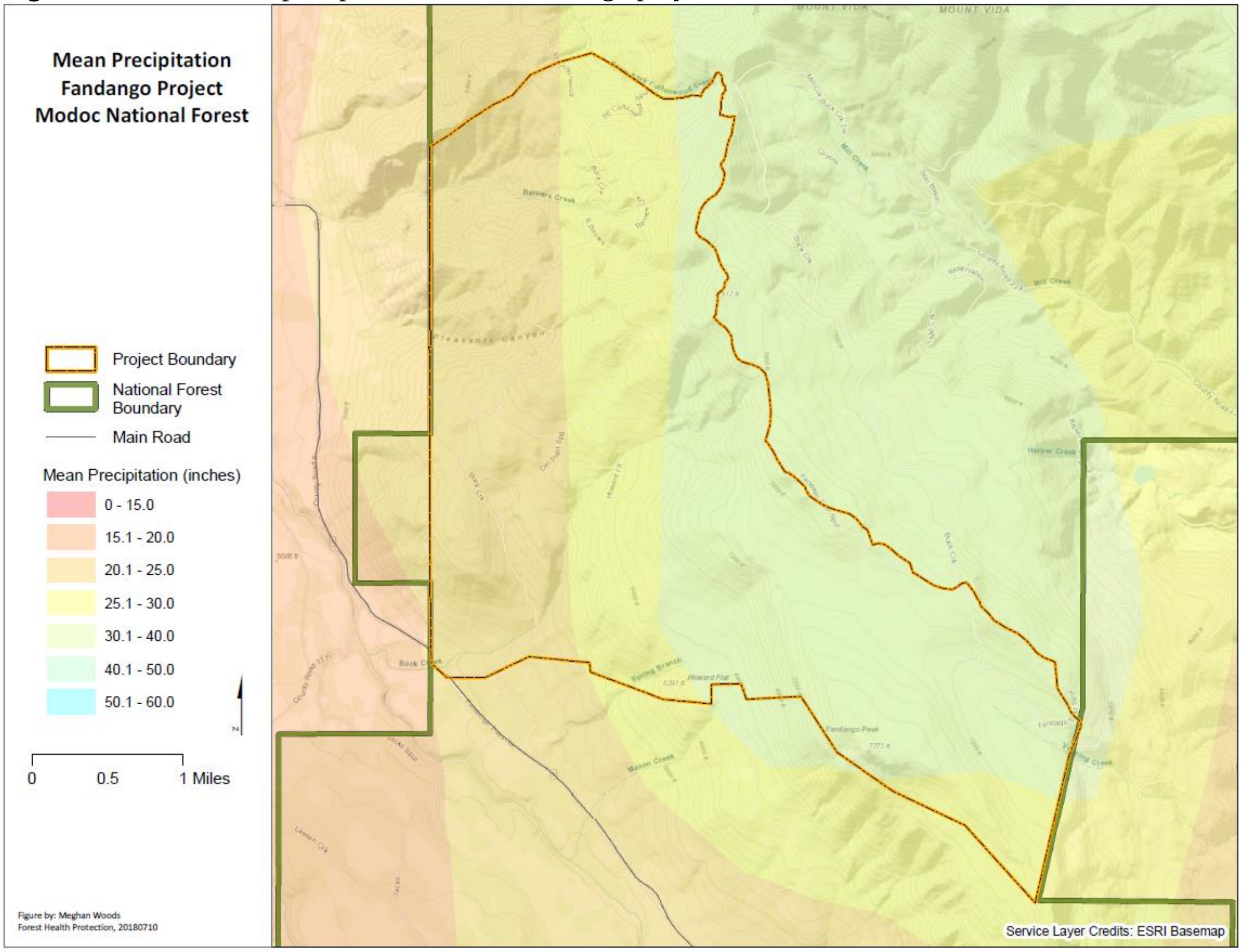


Figure 2. Mean annual precipitation for the Fandango project area.



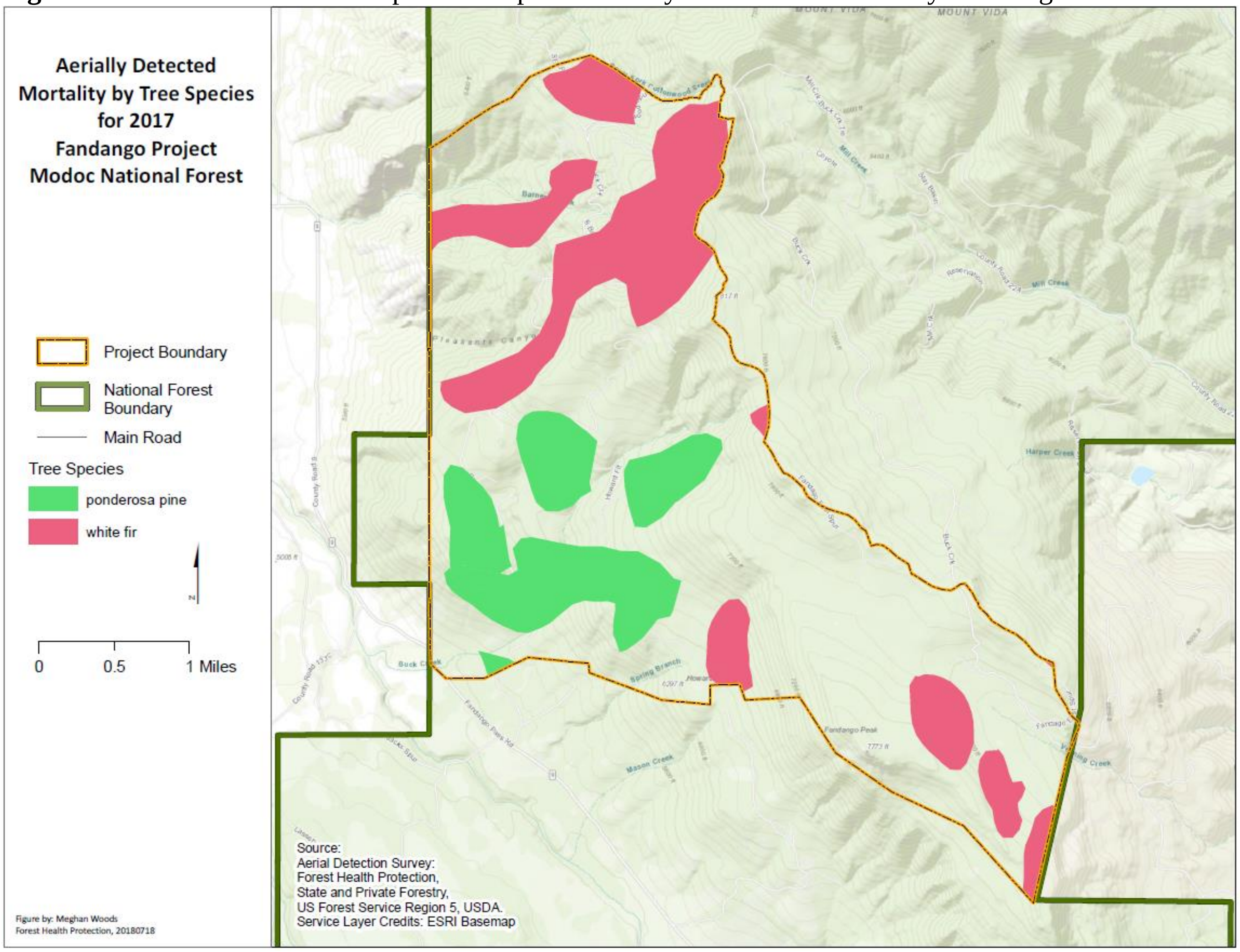
Forest insect and disease conditions

Bark beetle activity observed during the site visit was primarily on white fir where fir engraver beetle (*Scolytus ventralis*) has recently caused very high levels of tree mortality regardless of stand density. Some white fir mortality was also associated with Heterobasidion root disease (caused by *Heterobasidion occidentalis*, formerly referred to as S-type annosus root disease) and white fir dwarf mistletoe (*Arceuthobium abietinum* f. sp. *concoloris*) in many locations.

A few pockets of ponderosa pine mortality caused by western pine beetle (*Dendroctonus brevicomis*) were observed in dense stands growing on lower elevation sites.

Aerial detection surveys (ADS) in 2017 also mapped white fir and ponderosa pine mortality throughout the Fandango project area (Figure 3).

Figure 3. Extent of white fir and ponderosa pine mortality in 2017 as detected by ADS flight.



Stand conditions and mortality related to recent and future climate trends

Nearly all forested areas in the Fandango project area are above "normal" stocking levels and have exhibited elevated levels of tree mortality caused by bark beetles, especially during periods of drought (Figures 4 and 5; Table 1). This mortality combined with high stand density has resulted in heavy fuel loading in many areas and a corresponding increase in potential fire behavior.

Most stands have also experienced a species composition shift from shade intolerant ponderosa pine to more shade tolerant white fir in the absence of fire (Figure 6). This phenomenon is detailed for the southern Warner Mountains by Vale (1977) and summarized for low and mid montane zones of the entire Warner Mountains by Riegel et al (2006). Vale also described the near complete lack of yellow pine regeneration associated with the successful establishment of white fir; a condition that persists today in native stands. Egan et al (2010) describes the current dominance of white fir over ponderosa pine in Warner Mountain mixed species stands, especially in the younger age and smaller size classes.

Figure 4. Number of dead trees per acre mapped by ADS from 2008 to 2017.

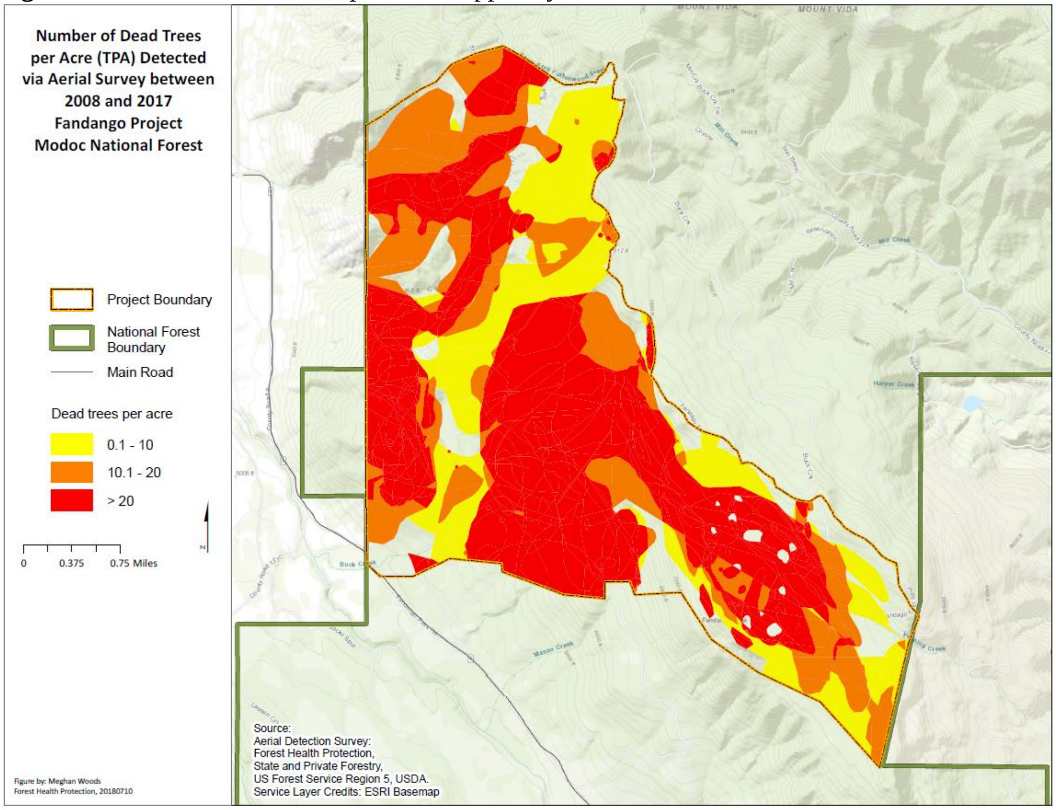


Figure 5. Number of years with elevated tree mortality mapped by ADS between 2008 and 2017.

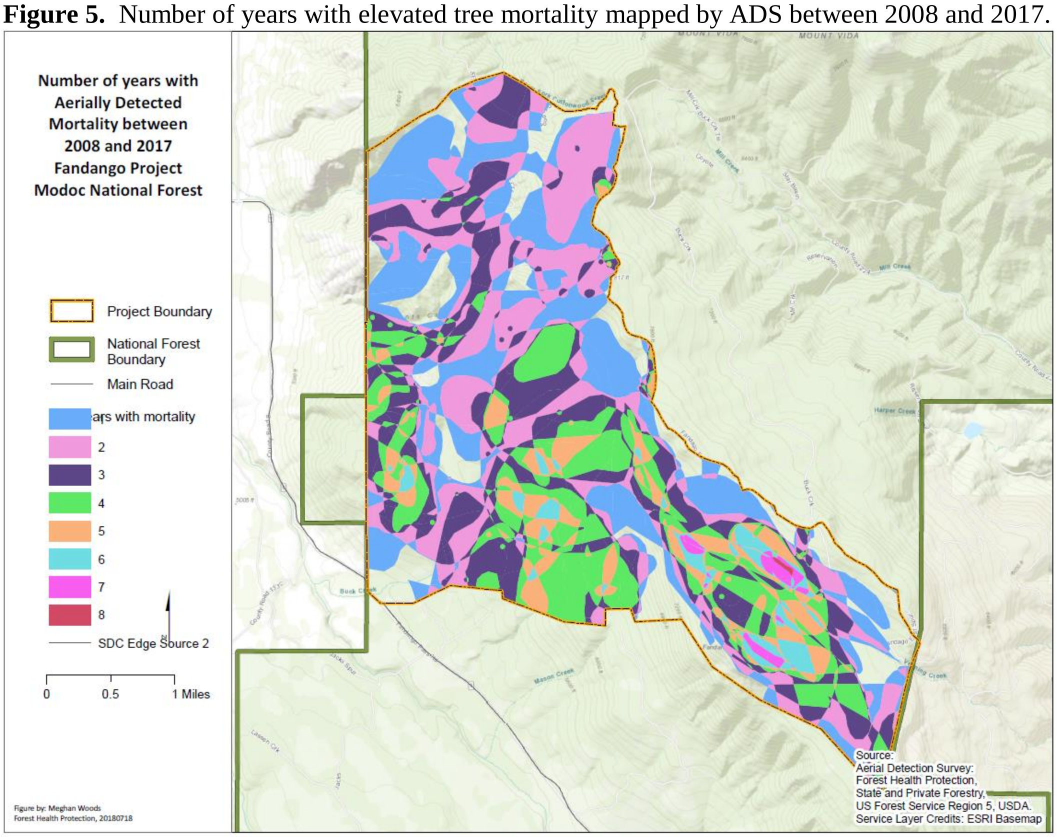


Table 1. Acres with mortality, estimated dead trees per acre and estimated total # of dead trees from R5 Aerial Detection Surveys and Palmer Hydrologic Drought Index (PHDI) (average of CA Divisions 2 and 3[1]) by water year (Oct-Sept) within the Fandango project area.

Year	Acres	Dead Trees/Acre	Total # of Dead Trees	PHDI[2]
2017	2,198	8.4	18,430	3.00
2016	3,984	12.6	50,130	-1.32
2015	3,353	15.2	51,131	-3.34
2014	901	4.9	4,408	-3.56
2013	2,210	6.1	13,427	-2.16
2012	1,207	8.1	9,829	-0.59
2011	1,150	6.8	7,784	2.78
2010	638	9.5	6,031	-0.14
2009	1,088	5.2	5,692	-2.98
2008	216	3.0	654	-3.16

[1] California Divisions 2 and 3 encompass most of northeastern California. The Fandango project area is on the border between these two zones.

[2] PHDI values ranging from -2.00 to -2.99 are considered moderate drought conditions. Severe drought conditions range from -3.00 to -3.99 and extreme drought conditions are below -4.00.

White fir is now abundant on many sites that are considered high to extreme risk for mortality during drought periods. The mortality resulting from the recent drought as well as previous droughts provides ample proof that these areas do not support healthy stands of white fir over the long-term. In the Fandango project area, fir engraver beetle-caused tree mortality has occurred over at least the last 10 years, reaching outbreak levels in 2015 and 2016 at the peak of the last drought (Table 1). In addition, there is still an abundance of dead and down white fir associated with the droughts of 1987-1992, 2001-2004 and 2007-2009 (Figure 7).

Figure 6. Old pine stump with fire scars. These are common in lower elevation stands that are now dominated by white fir with the absence of fire.

White fir that succumb to fir engraver beetle attacks are typically predisposed by other factors that compromise their health and vigor. In the Fandango project area, high stand density, prolonged drought, trees growing off site, dwarf mistletoe and Heterobasidion root disease are all contributing factors in declining tree health and mortality.

Nearly all of the low and mid elevation areas within these watersheds receive less than 30 inches of annual precipitation. This is below what is generally required for healthy white fir forests to exist over the long-term. Therefore, even at the lowest stocking levels, white fir growing on these sites are at a higher risk for fir engraver beetle-caused mortality during periods of drought.

Figure 7. Dead and down white fir from past fir engraver beetle outbreak.

The distribution of both white fir and white fir mortality are strongly influenced by the mean annual precipitation. The lower limit of precipitation in the natural range of white fir is about 20 inches (Fowels, H.A. 1965). The isohyetal map of mean annual precipitation provided in this report (Figure 2) can be used to rate the risk of white fir mortality (Schultz 1994, FHP Report 94-2).

Low risk: 40+ inches annual precipitation **(~0% of Fandango project area)**. These areas easily support stands of white fir. Mortality will be low, even during drought periods. Thinning will increase the rate of tree growth, but will show only slight differences in tree mortality.

Medium Risk: 30-40 inches of annual precipitation **(~50% of Fandango project area)**. Stands in these areas often have a high percentage of white fir that may achieve a considerable age and size. Prolonged drought may cause mortality of 5-10% of the stems. Periodic thinning which concentrates on removing white fir ingrowth will lower mortality by maintaining a more sustainable amount of biomass, as well as promoting a more stable mixed species stand.

High Risk: 25-30 inches of annual precipitation **(~25% of Fandango project area)**. In the absence of fire, these areas have stands which are dominated by densely stocked, small diameter white fir. The species distribution by age class shows an increase in the relative percentage of white fir in these stands following fire suppression. Prolonged drought may cause mortality in excess of 50% of the stems. The risk of mortality can be lowered by thinning to a wide spacing prior to the onset of drought, and by promoting a mix of species that are native to the site. *Note: this zone within the Fandango project area also includes larger diameter white fir that have also established following fire suppression. These trees should be targeted for removal as well as the*

smaller diameter white fir stems in order to establish and maintain a ponderosa pine fire-adapted system.

Extreme risk: 20-25 inches of annual precipitation **(~25% of Fandango project area**). In some cases the shade tolerant trees may live long enough to achieve an intermediate or co-dominant crown position. Prolonged drought may cause mortality of 80-85% of the stems. In stands where the total stocking of both overstory and understory is high, mortality may also occur in the pines. The risk of mortality may be lowered by managing groups of pine at wide spacing.

A white fir levels of growing stock study conducted by Cochran (1998) on the Deschutes and Fremont National Forests between 1983 and 1995 provides some additional information to consider when managing white fir in lower precipitation areas. Plots were thinned in 1982 and again in 1985 to a residual stand density index (SDI) of 112, 168, 224 or 280. These corresponded to growing stock levels of 20, 30, 40 or 50 percent of normal density. Elevations for his study plots ranged from 4,500 to 5,900 feet with average annual precipitation ranging from 16 to 31 inches. A general drought prevailed over the study areas from the late 1970's to the mid 1990's and mortality between 1991 and 1995 destroyed the study. Mortality on Blocks 2, 3 and 4 of the study was attributed to fir engraver beetles. Mortality from fir engraver beetles appeared to increase with increasing stand densities and was above acceptable levels even at the lowest stand density (20 percent of density considered normal for white fir).

From Cochran 1998:

"Healthy stands of white fir grow very rapidly, produce a dense crown cover, and are visually pleasing. These results, however, raise doubts about growing white fir stands on sites with mean annual precipitation rates below 32 inches even if stand densities are kept very low. The four widely scattered stands represented in this study apparently grew well for more than 60 years and reached commercial size before severe mortality occurred. Where significant amounts of white fir are present, managers need the ability to manipulate stand composition to minimize mortality. Future stands on similar sites should have a large component of ponderosa pine and should be managed by using ponderosa pine stocking guides (Cochran and others 1994). These density levels would allow the individual fir trees, intermingled with pine, to reach commercial size at fairly young ages. If drought, disease outbreaks, or severe insect infestations occur, the white fir could be removed, leaving ponderosa pine on the site. Ponderosa pine quickly responds to new growing space even at old ages and would quickly take advantage of the available site resources. Ferrell (1978) reports that trees under high moisture stress (-20 bars dawn xylem pressure or higher negative pressures) for protracted summer periods are more susceptible to successful fir engraver attacks than are trees under less stress. If prolonged droughts are forecast, removal of most of the white fir on drier sites may be advisable. This would prevent the buildup of fir engraver populations that could migrate to moist sites and inflict heavy damage where, historically, white fir has survived dry periods."

In a Warner Mountain study by Egan et al (2010), the density of fir engraver beetle-caused tree mortality was greater in unthinned versus thinned mixed conifer stands but the percentage of mortality relative to available host trees was similar. This further suggests that white fir growing in

high risk sites (based on average annual precipitation) are susceptible to drought and fir engraver-beetle caused mortality regardless of stocking levels.

From Egan et al (2010):

"Our findings varied in mixed conifer areas as the density of, but not percent, FEN (fir engraver beetle)-caused mortality was reduced in thinned areas. These results do not support the use of thinning to reduce percent mortality or the relative number of residual white fir trees susceptible to FEN-caused mortality during times of drought. Conversely, this study does support the efficacy of thinning to reduce the density of mortality or absolute number of beetle-killed trees in mixed conifer stands exposed to drought conditions. The density of residual white fir host and elevation (likely a proxy for water availability) were important factors associated with white fir mortality in our study. These findings indicate thinning effectiveness in reducing fir mortality was directly proportional to the amount of post-treatment density white fir retained. Thus, our findings support discriminating against residual fir and retaining a greater pine component, similar to historic compositions (Vale, 1977), during thinning treatments to reduce the density of FEN-caused mortality even during periods of drought."

Several Forest Health Protection reports since 1994 have also identified unhealthy white fir stand conditions on the Modoc National Forest, including the Warner Mountains, and the need for thinning (FHP reports available upon request). Most of these reports concurred that without treatment, the trend for most stands in the Warner Mountains of increasing stand density, high levels of insect and disease activity and elevated levels of tree mortality would likely continue until a major disturbance event such as a stand replacing fire occurred.

Predicted climate change is likely to impact trees growing in the Fandango project area over the next 100 years. Although no Modoc National Forest specific climate change models are available at this time, there is a general consensus among California models that summers will be drier than they are currently. This prediction is based on the forecasted rise in mean minimum and maximum temperatures and remains consistent regardless of future levels of annual precipitation (K. Merriam and H. Safford, *A summary of current trends and probable future trends in climate and climate-driven processes in the Sierra Cascade Province, including the Plumas, Modoc, and Lassen National Forests*. The risk of bark beetle caused tree mortality will likely increase for all conifer species under this scenario, especially drought intolerant white fir. Improving the resilience of stands to future disturbance events through density, size class and species composition management will be critical to maintaining a healthy forested landscape.

Considerations for thinning treatments

Low to mid elevation white fir/ponderosa pine stands (may be typed as mixed conifer) should be managed as ponderosa pine (eastside pine) stands as much as possible. This includes all white fir dominated stands with a ponderosa pine component. This will likely require a change from the current mixed conifer stand typing in many areas to ponderosa/eastside pine, better representing historic species compositions and desired future conditions. Having the ability to significantly reduce stand density and the abundance of white fir is critical to successful ecological restoration in this project area.

Thinning stands without significantly reducing stocking levels and the abundance of white fir will not likely result in a change in trajectory towards a pine dominated fire-adapted condition. A high residual component of white fir will continue to produce abundant seed, increasing the number of white fir seedlings relative to pine seedlings. Subsequent and frequent prescribed fire can help change the trajectory of seedling establishment towards pine but its use is often hampered by lack of appropriate burning conditions, air quality concerns or adequate resources for implementation. Even if prescribed burning is accomplished, is not likely to significantly reduce the number of larger diameter, seed producing white fir in thinned stands due to generally thicker bark and higher crown base heights.

When planning thinning treatments, it should be recognized that the target stand density and species composition is an average to be applied across the landscape and some variability may be desired. Individual high-value trees, such as mature pines, and drier areas dominated by ponderosa pine should benefit by having the stocking reduced to lower levels. Allowing for denser tree spacing and pockets of higher canopy cover may be desirable around potential wildlife trees, such as forked and/or broken-topped trees. Higher concentrations of white fir can be retained at higher elevations that receive >30" of average annual precipitation or on north facing slopes that receive 25 to 30" of average annual precipitation. Tree removal should include trees heavily infected with dwarf mistletoe, root disease and trees infested with bark beetles. Small group harvest could be utilized to remove white fir that are within known Heterobasidion root disease centers. This would create openings that could be planted with ponderosa pine or western white pine depending on elevation. These types of prescriptions would be consistent with 2014 Farm Bill Section 602(d)(1) direction that allows the implementation of projects "….to reduce the risk or extent of, or increase the resilience to, insect or disease infestation in the areas."

The District should reduce stand density to a level that significantly lowers the risk of bark beetle caused mortality. In most cases, thinning to a relative density of 25 - 40% (relative to the maximum Stand Density Index, or SDI) for a specific conifer species or for a weighted composition of conifer species will effectively reduce competition for limited water and nutrients and reduce the susceptibility to future bark beetle-caused tree mortality for many years. If deemed appropriate for the Warner Mountains, the District should consider an SDI max of 450 for drier pine-dominated mixed conifer (Long and Shaw 2005) and SDI max 550 (Long and Shaw 2012) for fir-dominated mixed conifer on more mesic north facing aspects. The District should also consider reducing the SDI in ponderosa pine dominated stands to well below 230. SDI 230 is the defined threshold for the zone of imminent bark beetle caused mortality (Oliver 1995). Thinning stands to this level will reduce the risk of additional bark beetle-caused mortality by reducing tree competition for limited water and nutrients. In addition to thinning, mixed conifer stands at the highest elevations should be managed to provide openings for western white pine regeneration, including the planting of rust-resistant seedlings if available.

It is recommended that a registered borate compound be applied to all freshly cut conifer stumps >14" in diameter to reduce the chance of creating new infection centers of *Heterobasidion irregulare* and *H. occidentale* formerly referred to as P-type and S-type annosus root disease, through harvest activity. An exception to this recommendation would be treating white fir stumps in ponderosa pine/white fir stands or more pure white fir stands if there is already a high level of

Heterobasidion root disease present. Treating white fir stumps in heavily infected stands is ineffective.

Western white pine should be retained as much as possible during any thinning operation in order to preserve genetic diversity, especially white pine blister rust (*Cronartium ribicola*) resistant individuals. An exception to this would be thinning suppressed trees within pure western white pine groups to reduce inter-tree competition. White pine blister rust, a non-native pathogen, has continued to weaken and kill this species over most of its range since its introduction into the Pacific Northwest in 1910. Identification and protection of local rust resistant trees for seed collection, if not already occurring, will aid in the future planting of rust resistant seedlings. Planting selected openings created through thinning operations with rust resistant stock would help insure this species persists in the area.

Forest Health Protection recently developed a treatment priority map for Region 5 to help land managers prioritize thinning treatments at the landscape level. This map depicts forested areas on National Forest System lands that are the most susceptible to drought and bark beetle-caused tree mortality based on forest type and stand density. These areas also meet the criteria of existing on slopes <=35% and being outside of wilderness areas, wild and scenic river corridors, designated roadless areas and California spotted owl protected activity centers. Additional criteria include not having burned at moderate to high severity since 1998 and not having been thinned since 2005. In addition to being overly dense, these areas have a history of tree mortality during drought resulting in heavy fuel loads and higher risk of stand replacing wildfire. Highest priority areas consist of high density pine stands, pine-dominated mixed conifer stands and fir-dominated mixed conifer and white fir stands growing on historically pine dominated sites. Second priority areas consist of high density fir-dominated mixed conifer and white fir stand on wetter sites. All mapped stands are California Wildlife Habitat Relationship size class 4, 5 and 6.

Figure 8 shows treatment priority areas within the Fandango project boundary. This mapping effort utilized remotely sensed data to create treatment priority layers for large scale planning and may not be accurate at the stand level. The forest should still use stand records and stand exam data to identify treatment areas and develop silvicultural prescriptions. An ALL LANDS version of the map was also created that includes wilderness areas, wild and scenic river corridors, designated roadless areas and California spotted owl protected activity centers to evaluate stand conditions in these protected areas. It also includes slopes >35% and all land ownerships (Figure 9).

Considerations for Rx fire

If prescribed fire is used as a follow-up treatment to stand thinning or as a standalone treatment, unacceptable levels of large diameter pine mortality may occur depending on management objectives. This mortality most often occurs as a direct result of cambium or crown injury to individual trees during the fire. Mature ponderosa are susceptible to mortality during prescribed burns because of the deep duff and litter that has accumulated at their base in the absence of fire. These duff mounds typically burn at a slow rate, while maintaining lethal temperatures, causing severe cambium injury. To protect individual large diameter pine from lethal cambium injury, raking the duff away from the bases of these trees before burning (within 24” of the bole and down to mineral soil) is recommended.

Potential for funding through the Western Bark Beetle Program

Forest Health Protection may be able to assist with funding, including NEPA activities, for thinning within the Fandango project area. Thinning treatments that reduce stand density and change species compositions sufficient to lower the risk to bark beetle-caused mortality would meet the minimum requirements for Western Bark Beetle Program funding and would be supported by this evaluation. If you are interested in this competitive funding please contact me for assistance in developing and submitting a proposal.
If you have any questions regarding this report and/or need additional information please contact Danny Cluck at 530-252-6431.

/s/ Danny Cluck

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Bill Moore, Forest Vegetation Manager, Modoc SO
Forest Health Protection, Regional Office

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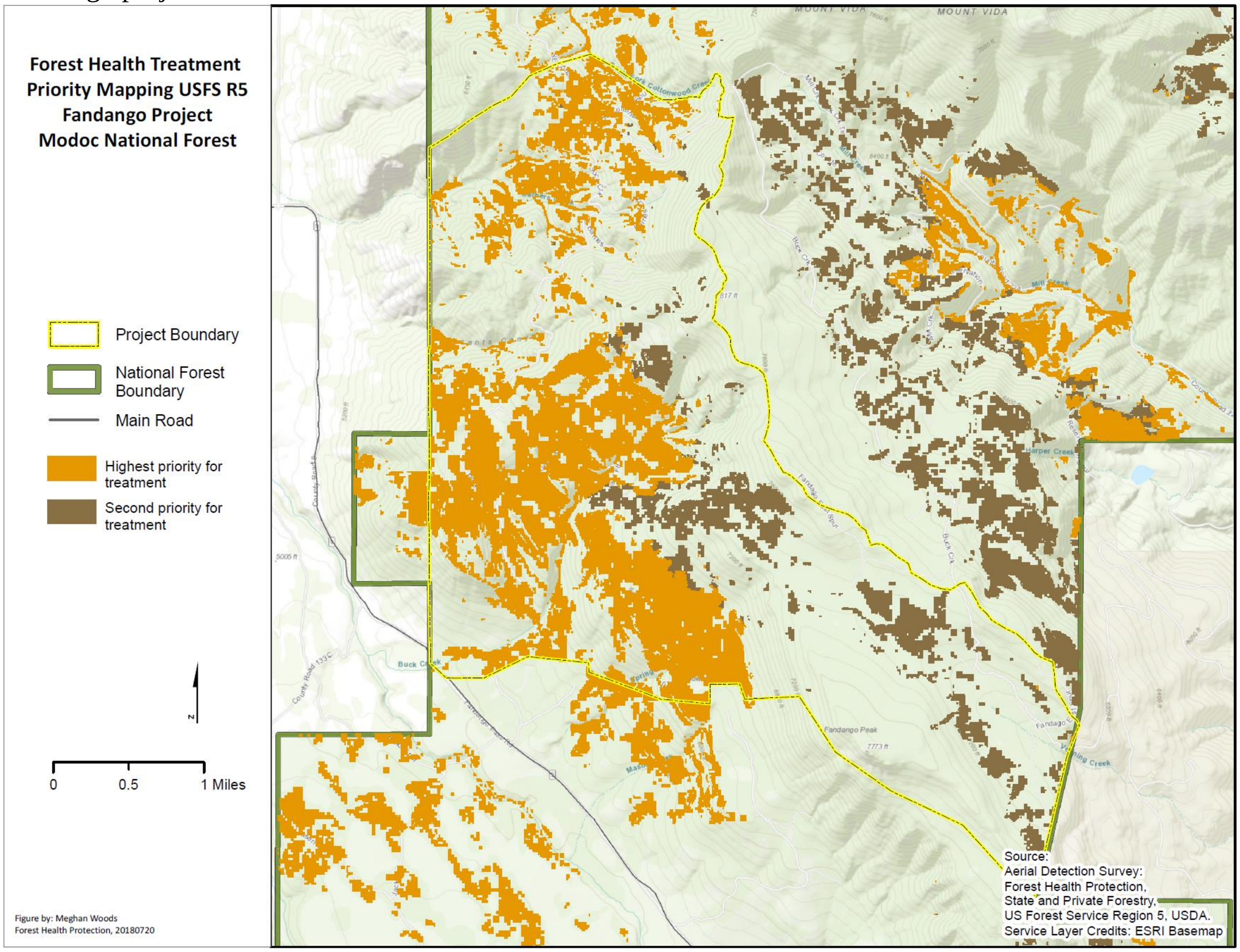
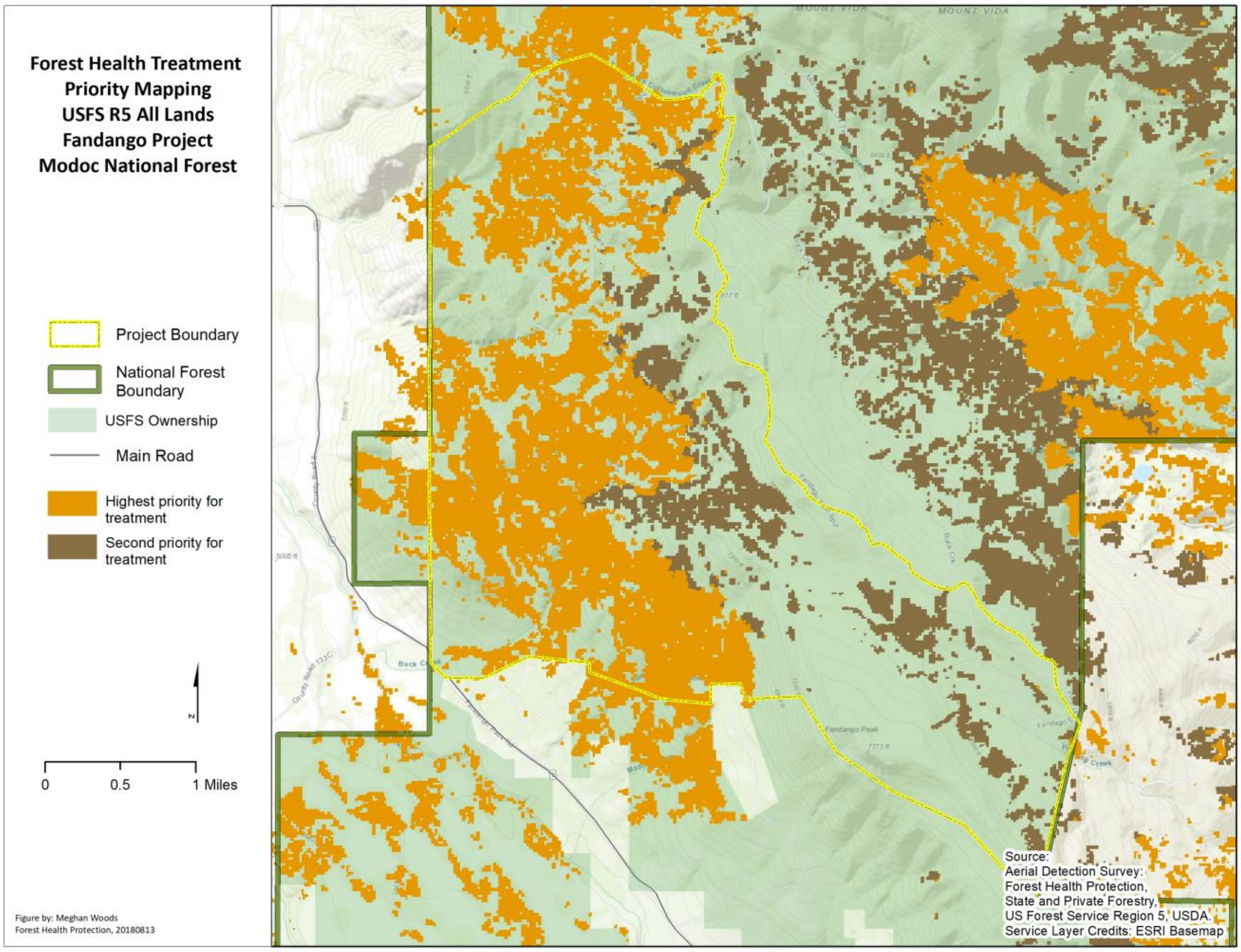
Figure 8. Treatment Priority Areas* at risk to bark beetle-caused tree mortality within and adjacent to the Fandango project area.



*Highest priority treatment areas include overly dense stands (>60% of maximum stand density index) of pine and pine-dominated mixed conifer stands as well as fir-dominated mixed conifer and white fir stands growing on historically pine-dominated sites. Second priority treatment areas include overly dense stands of fir-dominated mixed conifer and white fir. Mapped areas only include CWHR size class 4, 5 and 6 stands. Wilderness areas, inventoried roadless areas, wild and scenic areas, spotted owl protected activity centers, moderate to high severity burned areas since 1998, areas thinned since 2005, areas with >35% slope and all non-National Forest System lands were excluded from this analysis. Lodgepole pine, western white pine and whitebark pine stands, which may exist within the extent of this map, were also not included in this analysis.

Figure 9. Treatment Priority Areas (ALL LANDS version)* at risk to bark beetle-caused tree mortality within and adjacent to the Fandango project area.



*Highest priority treatment areas for ALL LANDS version include overly dense stands (>60% of maximum stand density index) of pine and pine-dominated mixed conifer stands as well as fir-dominated mixed conifer and white fir stands growing on historically pine-dominated sites. Second priority treatment areas include overly dense stands of fir-dominated mixed conifer and white fir. Mapped areas only include CWHR size class 4, 5 and 6 stands. Moderate to high severity burned areas since 1998, areas thinned or that experienced stand replacing disturbance such as clear cuts or bark beetle-caused tree mortality since 2005 were excluded from this analysis. Lodgepole pine, western white pine and whitebark pine stands, which may exist within the extent of this map, were also not included in this analysis.

Insect and Disease Information

Western Pine Beetle

The western pine beetle, *Dendroctonus brevicomis*, has been intensivly studied and has proven to be an important factor in the ecology and management of ponderosa pine thoughout the range of the host species (Miller and Keen 1960). This insect breeds in the main bole of living ponderosa pine larger than about 8 inches DBH. Normally it breeds in trees weakened by drought, overstocking, root disease, dwarf mistletoe or fire. Adult beetles emerge and attack trees continuously from spring through fall. Depending on the latidude and elevation, there can be from one to four generations per year.

Evidence of Attack

Initial attacks are made about mid-bole and subsequent attacks fill in above and below. Pitch tubes are formed on the tree trunk around the entry holes. Successful pitch tubes are red-brown masses of resin and boring dust. Relativly few, widely scattered white pitch tubes usually indicate that the attacks were not successful and that the tree should survive. Pheremones released during a successful attack attract other conspecifics. Attracted beetles may then spill over into nearby apparently healthy trees and overwhelm the tree with sheer numbers.

Life Stages and Development

These beetles pass thorugh the egg, larval, pupal and adult stages during a life cycle that varies in length dependent primarily on temperature. Adults bore a sinuous gallery pattern in the phloem and the female lays eggs in niches along the sides of the gallery. The larvae are small white grubs that first feed in the phloem then mine into the middle bark where they complete most of their development. Bluestain fungi inoculates the tree during successful attacks, blocking trachids and vessicles which contribute to the rapid tree mortality associated with bark beetle attacks.

Conditions affecting Outbreaks

Outbreaks of western pine beetle have been observed, and surveys made, in pine regions of the Westsince 1899 (Hopkins 1899; cited in Miller and Keen 1960). An insect survey completed in 1917 in northern California indicated that over 25 million board feet of pine timber had been killed by bark beetles.Information from surveys conducted in the 1930's indicated enormous losses attributed to the western pine beetle around that time. During the 1930's outbreak, most of the mortality occurred in stands of mature or overmature trees of poor vigor (Miller and Keen 1960). Group kills do not typically continue to increase in size though successive beetle generation as is typical with Mountain Pine Beetle and Jeffreay Pine Beetle. Rather, observations indicate that emerging beetles tend to leave the group kill area to initiate new attacks elsewhere.

The availability of suitable host material is a key condition influencing western pine beetle outbreaks. In northeastern California, drought stress may be the key condition influencing western pine beetle outbreaks. When healthy trees undergo a sudden and sever moisture stress populations of western pine beetle are likely to increase. Healthy trees ordinarily produce abundant resin, which pitch out attacking beetles, but when deprived of moisture, stressed trees cannot produce sufficient resin to resist the attack. Any condition that results in excessive demand for moisture, such as inter-tree completion, competing vegetation, or protracted drought periods; or any condition that reduces the ability of the roots to supply water to the tree, such as mechanical damage, root disease or soil compaction, can cause moisture stress and increase susceptibility to attack by the western pine beetle. Woodpeckers, predacious beetles, and low temperatures act as natural control agents when beetle populations are low (endemic populations).

Fir engraver beetle

The fir engraver attacks red and white fir in California. Fir engraver adults and developing broods kill true firs by mining the cambium, phloem, and outer sapwood of the bole, thereby girdling the tree. Trees greater than 4” in diameter are attacked and often killed in a single season. Many trees, weakened through successive attacks, die slowly over a period of years. Others may survive attack as evidenced by old spike-topped fir and trees with individual branch mortality. Although many other species of bark beetles cannot develop successful broods without killing the tree, the fir engraver beetle is able to attack and establish broods when only a portion of the cambium area has been killed.

Evidence of Attack

Fir engravers bore entrance holes along the main stem, usually in areas that are > 4” in diameter. Reddish-brown or white boring dust may be seen along the trunk in bark crevices and in spider webs. Some pitch streamers may be indicative of fir engraver attacks; however, true firs are known to stream pitch for various reasons and there is not clear evidence that pitch streamers indicate subsequent tree mortality or successful attack. Resin canals and pockets in the cortex of the bark are part of the trees defense mechanism. Beetle galleries that contact these structures almost always fail to produce larval galleries as the adults invariably abandon the attack. Pitch tubes, often formed when bark beetles attack pine, are not produced on firs.

Adults excavate horizontal galleries that engrave the sapwood; the larval galleries extend at right angles along the grain. Attacks in the crown may girdle branches resulting in individual branch mortality or "flagging". Numerous attacks over part or the entire bole may kill the upper portion of the crown or the entire tree. A healthy tree can recover if sufficient areas of cambium remain and top-killed trees can produce new leaders. The fir engraver is frequently associated with the roundheaded fir borer and the fir flatheaded borer.

Life Stages and Development

In the summer, adults emerge and attack new host trees. The female enters the tree first followed by the male. Eggs are laid in niches on either side of the gallery. Adult beetles carry the brown staining fungi, *Trichosporium symbioticum*, into the tree that causes a yellowish-brown discoloration around the gallery. The larvae mine straight up and down, perpendicular to the egg gallery. Winter is commonly spent in the larval stage, with pupation occurring in early spring. In most locations, the fir engraver completes its life cycle in 1 year; however at higher elevations 2 years may be required.

Conditions Affecting Outbreaks

Fir engravers bore into any member of the host species on which they land but establish successful galleries only in those that have little or no resistance to attack. Populations of less aggressive species like fir engraver are likely to wax and wane in direct relationship to the stresses of their hosts. Drought conditions often result in widespread fir mortality; however, attempting to determine when outbreaks will occur is difficult. Lowered resistance of trees appears to be a contributing factor. Overstocking and the increased presence of fir on sites that were once occupied by pine species may also contribute to higher than normal levels of fir mortality. Several insect predators, parasites and woodpeckers are commonly associated with the fir engraver and may help in control of populations at endemic levels.

Heterobasidion root disease

Heterobasidion spp. is a fungus that attacks a wide variety of woody plants. All western conifer species are susceptible. Madrone (*Arbutus menziesii*), and a few brush species (*Arctostaphylos spp.* and *Artemisia tridentata*) are occasional hosts. Other hardwood species are apparently not infected. The disease has been reported on all National Forests in California, with incidence particularly high on true fir in northern California, in the eastside pine type forests, and in southern California recreation areas.

Heterobasidion root disease is one of the most important conifer diseases in Region 5. Current estimates are that the disease infests about 2 million acres of commercial forestland in California, resulting in an annual volume loss of 19 million cubic feet. Other potential impacts of the disease include: increased susceptibility of infected trees to attack by bark beetles, mortality of infected trees presently on the site, the loss of the site for future production, and depletion of vegetative cover and increased probability of tree failure and hazard in recreation areas.

During periods favorable to the fungus, fruiting bodies (conks) form in decayed stumps, under the bark of dead trees, or under the duff at the root collar. New infection centers are initiated when airborne spores produced by the conks land and grow on freshly cut stump surfaces. Infection in true fir may also occur through fire and mechanical wounds, or occasionally, through roots of stumps in the absence of surface colonization. From the infected stump surface, the fungus grows down into the roots and then spreads via root-to-root contact to adjacent live trees, resulting in the formation of large disease centers. These infection centers may continue to enlarge until they reach barriers, such as openings in the stand or groups of resistant plants. In pines, the fungus grows through root cambial tissue to the root crown where it girdles and kills the tree. In true fir and other non-resinous species, the fungus sometimes kills trees, but more frequently is confined to the heartwood and inner sapwood of the larger roots. It then eventually extends into the heartwood of the lower trunk and causes chronic decay and growth loss.

Heterobasidion root disease in western North America is caused by two species: *Heterobasidion occidentalis* (also called the 'S' type) and *H. irregularis* (also called the 'P' type). These two species of *Heterobasidion* have major differences in host specificity. *H. irregularis* (‘P’ type) is pathogenic on ponderosa pine, Jeffrey pine, sugar pine, Coulter pine, incense cedar, western juniper, pinyon, and manzanita. *H. occidentalis* (‘S’ type) is pathogenic on true fir, spruce and giant sequoia. This host specificity is not apparent in isolates from stumps; with *H. occidentalis* being recovered from both pine and true fir stumps. These data suggest that infection of host trees is specific, but saprophytic colonization of stumps is not. The fungus may survive in infected roots or stumps for many years. Young conifers established near these stumps often die shortly after their roots contact infected roots in the soil.

Dwarf mistletoe

Dwarf mistletoes (*Arceuthobium* spp.) are parasitic, flowering plants that can only survive on living conifers in the Pinaceae. They obtain most of their nutrients and all of their water and minerals from their hosts.

Dwarf mistletoes spread by means of seed. In the fall the fruit ripen and fall from the aerial shoots. The seeds are forcibly discharged. The seed is covered with a sticky substance and adheres to whatever it contacts. When a seed lands in a host tree crown, it usually sticks to a needle or twig, where it remains throughout the winter. The following spring the seed germinates and penetrates the twig at the base of the needle. For the next 2-4 years, the parasite grows within the host tissues, developing a root-like system within the inner bark and outer sapwood, and causing the twig or branch to swell. Aerial shoots then

develop and bear seed in another 2-4 years.

Dispersal of dwarf mistletoe seeds is limited to the distance the seeds travel after being discharged. From overstory to understory, this is usually 20 to 60 feet, but wind may carry them as far as 100 feet from the source. A rule of thumb is that the seeds can travel a horizontal distance equal to the height of the highest plant in an infected tree. There is some evidence that long distance spread of dwarf mistletoe is occassionaly vectored by birds and animals.

Vertical spread within tree crowns of most dwarf mistletoes is limited to less than one foot per year because of foliage density. Because of the thin crowns of gray pine, however, the vertical rate of spread has been measured as being greater than 2 feet per year. This rate of spread equalled or exceeded the rate of height growth of infected trees.

Dwarf mistletoes are easy to identify because they are generally exposed to view within a tree's crown. Signs of infection include the yellow-green to orange mistletoe plants, basal cups on a branch or stem where the plants were attached and detached plants on the ground beneath an infected tree. Symptoms include spindle-shaped branch swellings, witches' brooms in the lower crown, and bole swellings.